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Review Article

Factors Affecting Shade of all Ceramic Restorations - A Literature Review

Mopkar M[1]*, Aras MA[2], Chitre V[3], Mysore A[4], Coutinho I[5] and Rajagopal P[5]

[1]Post Graduate Student (3rd Year MDS), Department of Prosthodontics, Goa Dental College and Hospital, Goa, India

[2]Professor and Head, Department of Prosthodontics, Goa Dental College and Hospital, Goa, India

[3]Professor, Department of Prosthodontics, Goa Dental College and Hospital, Goa, India

[4]Lecturer, Department of Prosthodontics, Goa Dental College and Hospital, Goa, India

[5]Assistant Professor, Department of Prosthodontics, Goa Dental College and Hospital, Goa, India

***Corresponding author:** Mitalee Mopkar, Post Graduate Student (3rd Year MDS), Department of Prosthodontics, Goa Dental College and Hospital, Mapusa, Goa, India

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Abstract

Purpose: The aim of this paper is to review the available literature on the different clinical and laboratory parameters that affect the final shade of an all ceramic restoration.

Study Selection: Over 40 articles that studied and reported the influence of different factors that play a role in the resultant ceramic shade were reviewed and included after an appropriate PUBMED search.

Results: Shade replication is a complex process affected by an interplay amongst multiple factors that can have an influence at different steps in the process of fabrication of a restoration. These include the type and shade of the substrate, the thickness of ceramic, and the opacity of porcelain, the number of firings, the luting cement and accelerated ageing.

Conclusion: Within the scope of this review, reported literature indicates that:

- Compositions of different core materials have varying masking abilities which need to be kept in mind before fabricating the restorations.
- Stump shade has no effect on the final shade outcome of all ceramic restorations of thickness greater than or equal to 2mm.
- Colour parameters are affected by varying the layering pattern or the ratio between the core and veneering ceramics.
- Repeated firings reduce the lightness (L*) values.
- Shaded luting cements result in a significant colour shift.
- Miscellaneous factors like surface topography and glazing procedures need more consideration.

Keywords: Ceramic; Shade; Substructure; Opacity; Number of firings

Introduction

With an increase in patient demand for aesthetically pleasing and natural looking restorations, all ceramic restorations have gained outstanding popularity. Creating a restoration that blends harmoniously with its natural counterpart requires accurate replication of its size, shape, surface texture, translucency and colour [1]. Matching the optical properties of natural teeth with artificial materials is quite challenging in dental practice. Over the past few decades, porcelain fused to metal crowns has been the predominating restorative approach for dental colour replication. However, the presence of an underlying metallic substructure, which is a total barrier to the transmission of light, gives the metal–ceramic crowns an unfavourable chromatic aspect [2] and limits their use in areas of high esthetic demand. The introduction of all ceramic systems in dentistry has revolutionised the outcome of fixed restorations. Unlike porcelain fused to metal crowns, all ceramic restorations allow greater light transmission thus improving the optical properties and colour and can hence be used in aesthetically demanding areas.

Colour and its elements such as hue, value and chroma; translucency and opacity; light transmission and scattering; and metamerism and fluorescence influence the esthetics of a dental restoration [3]. Colour assessment is considered a complex psychophysiologic process that is subject to numerous variables. Dentin is considered the primary source of colour, which is modified by the thickness and translucency of overlying enamel. The perceived colour of natural teeth is a result of reflected light from the enamel surface, in addition to the scattered light effect within enamel and dentin before being finally reflected back [4]. The amount of light that is absorbed, reflected and transmitted depends on the chemical nature and the size of particles within the core material compared to the incident light wavelength [5].

As these restorations are fabricated indirectly in a laboratory, dentists are required to provide the laboratory technicians with an accurate shade match in order to obtain optimal results. Shade selection relies greatly on a clinician's visual perception and is therefore often subjective. Furthermore, many a times even when an appropriate shade has been selected, the shade of the final restoration is influenced by a variety of laboratory procedures. The resultant colour of indirectly fabricated all-ceramic restoration does not always

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Table 1: Studies evaluating the influence of the type and shade of the substrate.

Year	Authors	Study Design	Study Outcome
2002	T. Nakamura et al. [8]	Used leucite based heat pressed ceramic system (Empress 2) in varying thicknesses (1.0, 1.2, 1.4, 1.6 1.8, 2.0 mm) over three different backgrounds (gold alloy, dentin porcelain in shade A1 & A4).	Gold alloy background resulted in higher L* (lightness) values as compared to the porcelain backgrounds. a*(red) and b* (yellow) values were greater for the gold-alloy specimens.
2006	Azer et al. [9]	Composite resin disks in 4 shades (A3, B3, C3 & D3) were layered with Ceramic in A2.	No statistically significant differences in the colour co-ordinates of the various specimen combinations tested.
2007	Yong-Keun Lee, Hyun –Suk Cha , Jin-Soo Ahn [10]	7 All ceramic core materials in A2 shade were layered with corresponding veneering ceramic in shade A2 and A3 to a final thickness of 1.5mm. The colour of the core, veneer and layering ceramic was measures with a reflection spectrophotometer.	The layered colour of different core and veneer combinations was different even though the thickness was set to 1.5mm and the shade was keyed to the same VITA tabs. The CIE L* value of the layered specimens was influenced by the CIE L* value of the core ceramic.
2009	Q. Li, H. Yu, Y.N. Wang [2]	Studied the optical influence of 10 shades of core build up resin composites on 3 all ceramic systems (IPS Empress 2, Vita Mark 2 and In -Ceram).	The colour of the underlying composite had a significant influence on the resultant colour of the all ceramic restoration. The Empress 2 system was found to be of a lower value than the Vita system.
2010	Moustafa Aboushelib, Alma Dozic. [11]	Natural and coloured (yellow) zirconia frameworks were layered using veneering ceramic (A1) either directly, over a layer of opaque masking liner or over deep chroma dentin.	The colour of zirconia framework produced a colour shift when compared to the target shade tab.
2011	Azer et al. [12]	Effect of 2 shades (Light A3, Dark C4) of composite resin substrates on two shades (transluscent, Opaque) of 0.5mm thick porcelain laminate veneers (IPS Empress).	Change in the shade of underlying composite substrate produced significant differences in the lightness L* and Chroma (C*ab) parameters of 0.5mm ceramic laminate veneer regardless of its shade.

Table 2: Studies evaluating the influence of the Thickness of ceramic.

Year	Authors	Study Design	Study Outcome
2000	Alessandro Vichi, Marco Ferrari, Carel Leon Davidson [13]	Ceramic disks of thickness 1.0mm, 1.5mm and 2.0mm were placed over four substrate materials-zirconia, carbon fiber, white experimental material, composite resin in shade A3.	The ∆E values decreased as the thickness of the ceramic increased with visually appreciable differences at 1.5mm and no clinically relevant differences at 2.0mm.
2000	Feimin Zhang, Guido Heydecke and Michael E. Razzoog [14]	Evaluated the colour difference that resulted from veneering 0.2mm aluminium oxide cores with 0.4mm porcelain in 3 shades (A1, A2 & B4).	Decrease of the L* coordinate and the increase of the a* and b* coordinates Differences of up to 22 E were found.
2003	Alma Dozic, Cornelis Johannes Kleverlaan, Marcel Meegdes , Jeff van der Zel , Albert Joseph Feilzer [15]	Evaluated the effect of changing thickness ratios of opaque porcelain (0mm, 0.25mm, 0.50mm, 0.75mm, 0.1mm) and translucent porcelain (1mm, 0.75mm, 0.50mm, 0.25mm, 0mm) in shades A1, A2 and A3 over a 0.75mm core.	Changes in the thickness ratios of opaque and translucent porcelain within the limited thickness produced perceivable differences in the samples.
2006	Tamer Shokry, Chiyayi Shen, Mohammed M. Elhosary, Adel M. Elkhodary [16]	Two different core materials: leucite reinforced feldspathic porcelain (IPS Empress) & Glass infiltrated magnesium aluminate (In-Ceram Spinell) were layered with corresponding veneering porcelain in varying thickness.	The core and veneer thickness and their interaction had a significant influence on the final appearance. L* values decreased for both ceramics. The core had a greater influence on L* values of the Spinell ceramic.
2007	F.D. Jarad, B.W. Moss. C.C. Youngson, M.D. Russell [17]	5 samples each of three shades (3M1, 3M2, 3M3) from the Vitapan 3D shade guide were made; consisting of 0.6mm opaque dentin, 0.8mm dentin & 0.6mm enamel porcelains. The enamel layer was then reduced to a thickness of 0.3mm.	Reducing the enamel thickness resulted in increase in the L*, b*, C*ab, h*ab values and decrease in the a* value.
2010	Ho-Jung Son, Woong-Chul Kim, Sang-Ho Jun, Young-Soo Kim, Sung-Won Ju, Jin-Soo Ahn [18]	Layered specimens consisting of 2.0mm ceramic core was layered with dentin porcelain in varying thickness from 0-2mm of 2 ceramic systems (IPS and LAVA) 3 shades (A1, A2 & A3.5).	Colour changes varied with ceramic brand, shade and dentin porcelain thickness.

match the target colour of traditional shade guides [2]. Douglas and Brewer [3] in their study found that the ability of commercial laboratories to reproduce the colour of the prescribed shade tab differed more than the acceptable clinical threshold.

Several factors affect the final colour of the restoration like the shade of the stump or substrate, the thickness of the layering porcelain, the number of firing cycles, luting cement etc. The consequent colour of the finished restoration is thus attributed to the cumulative effect of one or more contributing variables.

Need for Review

The aim of this article is to conduct a literature review in order to assess the effect of the various factors that play a role in influencing the resultant shade of all ceramic restorations.

Data Resources

A PUBMED search was conducted in order to obtain the articles. Keywords and phrases such as shade, colour, ceramic, porcelain, substrate, firing cycles, thickness, luting cement, artificial ageing etc. were entered individually and in combination. Article titles and abstracts published from the years 1973 to 2014 were evaluated for their relevance. A hand search of relevant publications was also conducted. The search was mainly focused on evidence based research as well as peer-reviewed literature on dental materials. However, only the articles published in English language were chosen. Articles involving studies conducted on metal ceramic specimens were excluded from this review. The selected articles have been included.

Table 3: Studies evaluating the influence of the opacity of porcelain.

Year	Authors	Study Design	Study Outcome
1990	B.K. Davis, S.A. Aquilino, P.S. Lund, A.M. Diaz-Arnold, C.E. [19]	Three groups of shade A1 ceramic were fabricated in changing levels of translucency (0%, 25% & 50%) and were luted to shade C4 resin substrate using clear cement. The shade was then matched to a shade tab by clinicians.	All the groups provided some masking effect of the substrate. i.e. from shade C4, shade C2. Varying the percentage of translucent porcelain had no effect on visual appearance.
1997	Peter Yaman, Sakib Riaz Qazi, Joseph B. Dennison, Michael E. Razoog [20]	Two porcelain materials in shade A2 were tested containing varying percentages (0, 25, 50 and 75%) of opaque modifier porcelain over a dark (grey) background.	Varying the percentage of opaque porcelain resulted in colour changes in all the samples.
2002	Heffernan MJ, Aquilino SA, Diaz-Arnold AM, Haselton DR, Stanford CM, Vargas MA [21]	6 all ceramic systems (IPS Empress Dentin, IPS Empress 2 Dentin, In-Cearam Alumina core, In-Ceram Spinell core, In-Ceram Zirconia core, Procera All ceram core) were tested for their relative contrast ratios at the appropriate clinically relevant thickness.	In decreasing order of translucency Vitadur Alpha (control) > In ceram spinell > IPS Empress, Procera all Ceram, IPS Empress 2 > In-Ceram Alumina > In Ceram Zirconia.
2002	Heffernan MJ, Aquilino SA, Diaz-Arnold AM, Haselton DR, Stanford CM, Vargas MA [21]	6 all ceramic systems (IPS Empress Dentin, IPS Empress 2 Dentin, In0Cearam Alumina, In-Ceram Spinell, In-Ceram Zirconia, and Procera All ceram) core+veneer were tested for their relative contrast ratios at the appropriate clinically relevant thickness to a final thickness of 1.5mm.	The opacity of all the core specimens was found to increase after veneering with their corresponding ceramics.
2007	Chu FCS, Chow TW, Chai J [7]	Evaluated the contrast ratios and masking abilities of 0.7mm thick veneers fabricated from 3 all ceramic systems (Procera, Empress 2, Vitadur Alpha) in shade A2.	The contrast ratios were significantly different Procera>Empress 2 >Vitadur Alpha.
2007	Uludag B, Usumez A, Sahin V, Eser K, Ercoban E [22]	Evaluated the effect of varying dentin ceramic thickness (0.5, 1, 1.5mm) on colour of leucite reinforced glass ceramic (IPS Empress) and glass infiltrated aluminium oxide (In-Ceram) ceramic systems.	Increasing the thickness significantly reduced the L* and increased the a* and b* values for in ceram. Substantial reductions seen in L* and a* values for IPS Empress.
2008	Ozturk O, Uludag B, Usumez A, Sahin V, Celik G [23]	Evaluated the effect of different dentin ceramic thickness (0.5, 1, 1.5mm) on the colour of lithium disilicate glass ceramic (IPS e.max) and zirconiu oxide (DC zirkon).	∆E increased with increasing thickness: (<3 for zirconia and > 3.7 for IPS emax). Increasing the thickness significantly reduced the L*. a* values increased for IPS Empress & DC Zirkon. b* values increased for IPS Empress.
2008	Ya-Ming Chen, Roger J. Smales, Kevin H.-K. Yip, Wei-Jia Sung [24]	Tested 4 ceramic systems (Empress 2, In-Ceram Alumina, In-Ceram Zirconia, Cercon base) in 0.5mm thickness.	In order of decreasing translucency: IPS Empress 2>In-Ceram Alumina>IN-Ceram Zirconia = Cercon Base.
2011	Vinay Chila Bachhav, Meena Ajay Aras [25]	Zirconia (Lava, 3m ESPE) specimens were veneered with varying ceramic thicknesses (0.5, 1, 1.5 mm).	Increasing the thickness significantly reduced the L* whereas an increase in the a* and b* values were seen.
2014	Sevcan Kurtulmus-Yilmaz, Mutahhar Ulusoy [26]	Compared the translucency of 3 Zirconia all ceramic systems (In-Ceram zirconia, ICE Zirkon & Katana) in 3 shades (A1, A2 & A3.5) with lithium disilicate.	The translucencies of the zirconia core specimens were significantly lower than that of lithium dislilicate. The translucencies decreased after veneering.
2014	Husain Hatim Harianawala, Mohit Gurunath Kheur, Sanjay Krishnaji Apte, Bharat Bhanudas Kale, Tania Sanjeev Sethi, Supriya Mohit Kheur [27]	Compared the transmittance of translucent zirconia with conventional zirconia, conventional lithium disilicate and high translucency lithium dilsilicate.	The transmittance values of conventional lithium dislocate were significantly higher than the translucent zirconia tested.

Type and Shade of the Substrate

Different ceramic materials have been used as copings in all ceramic restorations (e.g. feldspathic porcelain, lithium disilicate, alumina, zirconium oxide) [6]. The zirconium oxide and lithium disilicate substructures are stronger and therefore can be comparatively thinner whilst still successfully masking a dark (black) background [7]. The type of all-ceramic substructure used has a large influence on the final colour of sample produced which depends on the inherent properties of the material. A Summary of the studies conducted on the influence of the type and shade of the substrate is illustrated in Table 1.

Thickness of Ceramic

Even though the substrate may contribute majorly to the colour of the restoration, it is further influenced by the thickness and the translucency of the overlying ceramic. All ceramic systems require the combination of 2 layers of ceramic material, such as a strong ceramic core and veneering porcelain, with different opacities, shade and thickness, to provide a natural appearance. Along with the clinician's ability to match colour correctly, the technician's skills for porcelain build up are equally necessary. A Summary of the studies conducted on the influence of the thickness of ceramic is illustrated in Table 2.

Porcelain Opacity

Thickness and Opacity are co-variables that affect the optical properties of the ceramic. In order to conceal a discoloured tooth or a metal post, it is essential for a ceramic material to have good masking ability to prevent unpleasant display of underlying metal. A Summary of the studies conducted on the influence of the opacity of porcelain is illustrated in Table 3.

Repeated Firings

A Summary of the studies conducted on the effect of the number of firings is illustrated in Table 4.

Table 4: Studies evaluating the effect of the number of firings.

Year	Authors	Study Design	Study Outcome
2007	Uludag B, Usumez A, Sahin V, Eser K, Ercoban E [22]	Evaluated the effect number of firings (3, 5, 7) on colour of leucite reinforced glass ceramic and glass infiltrated aluminium oxide ceramic systems.	Repeated firings resulted in reduced L* values and darker specimens. Increase in the a* and b* values resulting in redder and yellower specimens.
2008	Ozturk O, Uludag B, Usumez A, Sahin V, Celik G. [23]	Evaluated the effect of number of firings (3, 5, 7, 9) on the colour of lithium disilicate glass ceramic (IPS e.max) and zirconiu oxide (DC zirkon).	Increase in the number of firings resulted in increase in L* values for IPS The a* and b* values showed increase at lower thickness levels.
2011	Vinay Chila Bachhav, Meena Ajay Aras [25]	Zirconia (Lava, 3m ESPE) specimens were veneered with varying ceramic thicknesses (0.5, 1, 1.5mm). Samples were evaluated after repeated firings (3, 5, 7, 9).	Increase in the number of firings resulted in increase in L* values for 0.5mm and 1.5mm whereas it decreased for 1mm. a* values increased for 1mm & 1.5mm and decreased for 0.5mm. b* values increased for all thicknesses.
2014	Kerem Yılmaz, Fehmi Gonuldas, Caner Ozturk [28]	Two ceramic cores (IPS Empress esthetic & IPS Empress 2) and 1 metal (Ni-Cr) core were veneered with corresponding 1mm porcelain and Glazed. Repeated firings were performed (1, 3, 5, 7 cycles).	Repeated firings resulted in perceivable colour changes. (E>3.7). L* values were found to be higher.

Table 5: Studies evaluating the influence of the luting cement.

Year	Authors	Study Design	Study Outcome
2009	John Chang, John D. Da Silva, Maiko Sakai, Joshua Kristiansen, Shigemi Ishikawa-Nagai [29]	3 composite luting cement systems (Variolink II, Esthetic, Nexus II) were evaluated in 0.1mm thickness for 2 systems lithium disilicate (empress) & zirconia (katana)	Significant differences were seen in ∆E values amongst the three areas of the crown tested.
2009	Hakan Terzioglu, Burak Yılmaz, Bengul Yurdukoru [30]	Determined the effect of two different shades A1 & A3 of resin luting cements of four thicknesses (0.5, 1, 2, 3 mm) of IPS Empress.	Following cementation the ∆E values between the two shades was not statistically significant. But the ∆E values after cementation were statistically significant from baseline values for both the shades.
2011	Evren Kilinc, Sibel A. Antonson, Patrick C. Hardigan, Atilla Kesercioglu [31]	3 resin cement systems (Nexus-2, Appeal, Calibra) In their Light cure and Dual cure forms were luted to lithium disilicate (IPS Empress) disks. Colour measurements were done before and after 65 hours of accelerated ageing.	The LC cement group did not produce visible discoloration. (E<2) or a significant shift in L*a*b* parameters. The DC group discoloured more than the LC group. With a colour shift towards yellow.
2011	Gloria Beatriz de Azevedo Cubas, Guilherme Brião Camacho, Flávio Fernando Demarco, Tatiana Pereira-Cenci [32]	6 ceramic systems (Vitadur Alpha, Noritake Super Porcelain EX-3, Vision – Esthetic, IPS Classic, All Ceram, Vintage Halo) in three thicknesses (1, 1.5, 2 mm) were placed on a dark C4 shade background. 2 cements were tested–opaque and A3.	At 1.5 & 2mm thickness, L*, a* & b* values increased. The use of opaque cement resulted in an increase in the L*, a* & b* values.
2013	Sedanur Turgut and Bora Bagis [33]	4 shades (A1, A3, EO & ET) of leucite reinforced glass ceramic (IPS Empress) were made in thicknesses 0.5 & 1mm. Two dual polymerizing and two light polymerising cement systems were tested: Rely X Veneer (A1, A3, Tr, WO), Variolink Veneer (+3, MO, -3), Maxcem Elite (Clear, WO Yellow, White) and Variolink II (Tr, WO).	All resin cement shades affected the colour of the veneers.

Luting Cement

A Summary of the studies conducted on the influence of the luting agent is illustrated in Table 5.

Accelerated Ageing

A Summary of the studies conducted on the effect of the accelerated ageing is illustrated in Table 6.

Discussion

In order to achieve a restoration that mimics the appearance of a natural tooth, it is necessary to perform two important steps: (i) to select the best possible shade, using a shade guide and/or an electronic shade taking instrument and (ii) to reproduce this shade with an appropriate dental material [36].

Seghi et al. [4] have stated that any organized shade selection procedure requires a colour standard to which an object can be compared to or matched. Shade guides should have basic requirements in colour matching including the logical arrangement within the colour space and adequate distribution within colour space of natural teeth [37]. However, in a study conducted by Li et al. [2] it was seen that the final color could hardly match the traditional shade guide. According to ADA guidelines, a difference of upto $2\Delta E^*_{ab}$ units can exist between shade tabs of the same numeric shade [10,26].

The outcome of the restoration is also dramatically influenced by the effect of illumination and lighting conditions [9-11] and a color match between two objects under one illuminant may become a mismatch under a different illuminant, due to metamerism during shade record [38].

Most of the current commercial shade taking devices follow the CIELab* system developed in 1976 and 1978 by Commission International de l'Eclairage wherein L* represents the degree of lightness/darkness, a* represents the degree of redness/greenness & b* represents the degree of yellowness/blueness. The difference between two co-ordinates is calculated as ∆E [36]. The value at which ∆E was considered visually perceivable and clinically relevant has been debated. Ragain et al. [39] reported the average acceptability

Table 6: Studies evaluating the effect of accelerated ageing.

Year	Authors	Study Design	Study Outcome
2001	Guido Heydecke, Feimin Zhang, Michael E. Razzoog [34]	0.2mm aluminium oxide (Procera) discs were veneered with 0.4mm thick veneers in 2 shades (A1 & B4) and bonded to a grey acrylic resin substrate. Measurements were repeated after 300 hours of accelerated ageing.	The L* values increased in all the groups, but not significantly. Slight decrease in the chroma co-ordinates (a* & b*).
2008	Arzu Atay, SelçukOruç, Jülide Ozen, Cumhur Sipahi [35]	Colour stability of feldspathic ceramic in shade A2 was tested after 4 types of surface treatments: Self–Glazing, Dual–ion exchange, overglaze, polishing. Colour measurements were repeated after 150 & 300 hours of accelerated ageing.	Polished test samples showed the highest colour difference amongst the 4 groups. Accelerated ageing resulted in a colour shift towards yellow and brighter samples.

threshold to be ΔE=2.72. Johnston and Kao [38] analysed the relationships between instrumentally derived colour differences and EVRSAM visual rating scale suggested that perceived appearance within the dental environment is too complex to be completely defined by three color parameters and established the limit as ΔE=3.7 as an acceptable match [38]. This value has been used as benchmark reference for several investigations.

In a clinical study performed by Douglas and his co-workers [40] the predicted value at which 50% of operators could perceive colour difference was 2.6 ΔE*ab. But the predicted value at which 50% of the dentists would refabricate the restoration due to a mismatch in colour was 5.5ΔE^*_{ab} units.

The supporting tooth structure or esthetic restorative foundation material provides the primary source for restoration colour [12]. The study by Li et al. [2] demonstrated that of the three parameters, the ΔL* (lightness) value of the core, which is a result of light reflection, had maximum contribution towards colour differences. This effect is more pronounced in porcelain fused to metal restorations as compared to metal free restorations because surface of metal is more reflective than porcelain [8].

The type of all ceramic substructure used had an influence on the final colour of the sample. Lee et al. [10] in their study found differences of upto 10L* and 8b* units across the range of core materials tested. (Zirconium oxide, feldspathic porcelain, alumina, hot pressed ceramic). When the colour of the coping was measured prior to the application of the veneering ceramic, leucite reinforced ceramics (IPS Empress) were found to be less yellow and darker than glass reinforced alumina (In-Ceram) [2,10] even after layering with their corresponding veneering ceramics [10].

Similar results were obtained in the investigation by Shokry et al. [16] who found leucite reinforced ceramics to have a higher b* value and more yellow component.

Also, the leucite reinforced ceramic specimens produced lower ΔE values (1.4-3.1) than the alumina equivalent (4.3-7.8)

Increasing the overall thickness demonstrated an increase in the brightness parameter L* along with the yellowness and redness of the restorations [15,16]. So also the ΔE values. Conversely, in another study [8] it was found that as the thickness of the specimen increases the L* value was found to decrease. This was probably because of the decreased light reflectance by the background.

Regardless of the ceramic shade, with an increase in the thickness of the ceramic veneer, the light transmission is significantly reduced [12,41].

All ceramic restorations also often require the combination of two or more layers, such as a strong ceramic core and a veneering porcelain, with different opacities, shades and thickness. The all ceramic restoration replicates the tooth that comprises of dentin and enamel with layering of the corresponding opaque and translucent porcelain respectively.

The colour co-ordinates of all ceramic core-veneer layered restorations are influenced by the colour co-ordinates of the constituent layers [10].

Along with the clinician's ability to match colour correctly, the technician's skills for porcelain build up are equally necessary. Layering the various porcelain shades in a freehand technique lacks consistency [15]. With CAD/CAM, the thickness of the individual constituent layers can be controlled by milling them at a predetermined thickness [12,15].

Dozic et al. [15] evaluated the effect of changing ratios of opaque and translucent porcelain in three different shades within a limited thickness of 1.70mm. The increase in the thickness of the opaque porcelain(and consequent decrease in translucent porcelain) had a greater effect on the L* values of the lighter (A1) shades which was probably because the relatively more opaque A3 shade allowed less influence of the underlying layer. An increase in dentin porcelain thickness from 0-2mm, showed decrease in the L* values and increase in the a* and b* values [18] also the aluminium oxide based ceramic showed smaller colour changes as compared to the lithium disilicate equivalent. It was also noticed that when the dentin porcelain thickness was above the critical value, increase in the dental porcelain thickness produced minimal changes in the CIE a* and b* values [18].

Jarad et al. [17] investigated the influence of the outermost enamel porcelain by evaluating the effect of its changing thickness from 0.6mm to 0.3mm. The reduction in thickness increased the L*, b* and chroma. This effect was more pronounced for the lighter shades 3M1 than the darker 3M2 and 3M3. Whereas for b* and chroma, the effect was more pronounced on the darker shades 3M3,and when the thickness was 0.3mm as compared to 0.6mm. Average increase of 5.5ΔE was noted which is higher than the acceptable threshold. As the thickness of enamel increases, the CIELAB values move from those of the underlying dentin to that of enamel. Increased proportion of dentin porcelain resulted in increase in chroma and resulted in a more intensive final colour whereas, increasing the enamel thickness decreased it.

Controlling the colour therefore becomes more and more challenging as the number of constituent layers increases. The reduction of tooth structure during preparation must be adequate enough to allow proportioning of the different layers. Also, the reflectance parameter was found to change exponentially with increasing thickness [17].

Thickness and Opacity are co-variables that affect the optical properties of the ceramic. Kelly et al. [42] identified core translucency as one of the primary factors that governs the esthetics as optical properties of all ceramic restorations.

Although the thickness of the material is shown to proportionally increase the opacity [5], increasing the ceramic thickness in order to gain opacity either requires over reduction of tooth structure or the fabrication of a bulky and over contoured restoration.

The translucency of dental porcelain is largely dependent on light scattering. If the majority of light passing through a ceramic is intensely scattered and diffusely reflected, the material will appear more opaque. If only part of the light is scattered and most is diffusely transmitted, the material will appear more translucent. The amount of light that is absorbed, reflected, and transmitted depends on the crystal content within the core, its chemical nature, and the size of the particles. Based on the composition, ceramic materials are available with varying degrees of inherent opacities. Also, the strengthening components added to the different ceramics have differing crystalline contents and refractive indices [5]. Heffernan et al. [5] in their study proved that at the same core thickness of 0.5mm, different materials showed a range of contrast ratios. An older study reported by Lund et al. [43], gives contrasting results with higher values of opacity reported for Empress, In- Ceram Alumina and In-Ceram Spinell specimens of 1.5mm thickness. However the thickness of the samples used in this study were greater than the manufacturer recommendations. Translucency of ceramics is often associated with lower L* values [16].

In order to conceal a discoloured tooth or a metal post, it is essential for a ceramic material to have good masking ability at clinically relevant thickness to prevent unpleasant display of underlying discoloured substrate. Vichi et al. [13] in their study performed on a commercially available glass ceramic (IPS Empress), demonstrated successful masking of the underlying substrate at a thickness of 2mm and mentioned that substrate aspects need attention at the lower thickness values tested (1 and 1.5mm).

Another method of evaluating the masking ability of a material is by calculating the contrast ratio; which is defined as the ratio of illuminance (Y) of the test material when it is placed over a black background (Yb) to the illuminance of the same material when it is placed over a white background (Yw) [7]. The contrast ratios and masking abilities are governed by the composition of the core and veneer, the particle sizes and also the thickness of the material used and the volume of the crystals. Procera all Ceram has 99% aluminium oxide crystals in the matrix whereas Vitadur has 10% aluminium oxide crystals in a feldspathic matrix [7]. The contrast ratio of the In-Ceram Spinell system is reported to be lower than that of the leucite reinforced ceramic system (0.67 vs. 0.72) [21] This is because leucite reinforced ceramics (Empress) and lithium disilicate based ceramics (Empress 2) have lesser crystalline content in the matrix than the Alumina based ceramics (Inceram, Procera) [5] making them more translucent by allowing greater transmission on light.

Translucency of dental porcelains is known to be affected by a number of factors such as grain boundaries, pores, second phase of component and light scattering from rough surfaces [10,44].

Presence of porosities has an effect on the transmittance due to variation between the refractive indices of air and the ceramic particles. Lithium disilicate with minor porosities has good transmittance unlike zirconia with large porosities [27].

The final colour of all ceramic restorations is also influenced by the cement shade. Vichi et al. [13] evaluated the effect of varying cement shade and thickness (0.1mm and 0.2mm) under a ceramic disk of 1.00mm. The colour changes caused by varying the cement thickness or shade were only detected instrumentally. At a clinically relevant thickness of greater than 1mm, this effect would be negligible. In opposition, another study [9] showed that the underlying cement shade had no significant effect on the colour. Resin cements have been reported to undergo external and internal discoloration [45]. Internal discolouration has been addressed as a change in the material chemistry e.g. Formation of oxygen by products [46] in chemically activated resin cements like dual cure and auto cure due to the oxidation of reactive groups like accelerators and inhibitors maybe responsible for colour change. Consistently, in an investigation by Kilnic et al. [31] dual cure cements produced more colour change, but none of the cements produced significant colour changes in the samples tested (ΔE 2.5 highest). In contrast, another study [33] showed vast colour changes (ΔE ranged from 9.8-0.9).

Similarly the investigation by Terzioglu and co-workers [30] demonstrated $\Delta E>3.7$ pre and post cementation for cement thickness of 2 & 3mm.

The same author also stated that translucent ceramics result in greater curing of the underlying resin cement which is attributed to the greater transmission of the incident curing light.

When 3 different cement systems were tested, the shades with the same designations (white/yellow/opaque) did not match in the CIELAB colour space [29]. Balderamos [47] observed significant colour differences between resin cements and their corresponding trial insertion pastes.

Additional firing may increase the leucite content and consequently the opacity [21] which is not the case with alumina containing ceramics that can be subject to repeated firing without loss of translucency. The cause of colour change may be because of pigment breakdown occurring at firing temperatures, as the metal oxides used to impart hue stains may not be colour stable at these temperatures [22]. In Ceram produced changes (ΔE 1) between 3-5 firings only at low thickness of 0.5mm, whereas IPS Empress produced changes (ΔE 1 or greater) at all thicknesses tested between 3-5 and 3-7 firings [22]. These contradict O'Brien's [48] findings that report perceivable colour change at upto 6 times firing.

Barghi [49] reported that repeated firings could cause an increase in the density by decreasing the trapped air bubbles thus resulting in colour change.

Yilmaz et al. [28] in their study state that continuous and/or high temperature firing could cause pyroclastic stream with surface accumulation. Also, recrystallization and devitrification of the ceramic was observed.

Kim et al. [50] stated that the surface texture has an effect on the L* value. And this parameter was higher for a glazed surface than on a polished surface. Yilmaz et al. [28] found differences in the translucency parameters of the specimens post-glazing. Similar results were seen in the investigation by Heffernan et al. [21] where significant differences were found between the glazed and non-glazed specimens.

In another study by Kim [50], monolithic zirconia specimens stained 1, 2, 3, 4 & 5 times were analysed for the colour stability after glazing and polishing. Glazing and polishing lowered the L* values.

A reason for conflicting results seen in the investigations performed could be because different studies use different colour measuring devices and different measuring geometry which makes the comparison of colour co-ordinates difficult [6].

The studies included lack in standardization protocols in terms of method and reliability of the measurements, preparation of the samples (manufacturer's instructions powder liquid ratio [51], shade, thickness of veneering ceramic).

Conclusion

On the basis of the articles reviewed, the following conclusions can be drawn:

- Shade selection and replication is a complex process affected by the interplay amongst numerous factors.
- Core materials of different compositions have varying masking abilities which need to be evaluated whilst fabricating a restoration of clinically relevant thickness.
- Stump shade has no effect on all ceramic restorations of thickness 2mm or greater.
- Varying the layering pattern as well as the ratio of the layered core and veneer porcelain affects the colour parameters.
- Repeated firings result in darker restorations by reducing the lightness (L*) parameter.
- Shaded resin luting cements produce a significant colour shift.
- Other factors like the surface topography, glazing procedures also need to be considered.

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